TECHNICAL NOTES

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SOME CHARACTERISTICS OF FUEL SPRAYS AT LOW-INJECTION PRESSURES

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Summary

This report presents the results of tests conducted at the Langley Memorial Aeronautical Laboratory, Langley Field, Va., to determine some of the characteristics of the fuel sprays obtained from an 0.008-inch and a 0.020-inch open nozzle when injection pressures from 100 to 500 pounds per square inch were used. Fuel oil and gasoline were injected into air at densities of atmospheric and 0.325 pound per cubic foot.

It was found that the penetration rate at these low pressures was about the same as the rate obtained with higher pressures. Spray cone-angles were small and individual oil drops were visible in all the sprays. Gasoline and fuel oil sprays had similar characteristics.

Introduction

Interest has recently been shown in spark-ignition engines using gasoline or Diesel oil and having the fuel injected into the inlet manifold or into the engine cylinder during the suction and compression stroke when the air density is low. Since in this type of engine injection pressures of several thousand pounds per square inch are not required to give the necessary fuel spray penetration with round-hole orifices, a low-pressure injection system could be used, provided that the low-injection pressure gave sufficient atomization and dispersion of the fuel spray. Consequently, it seemed desirable to investigate the characteristics of the sprays produced with low-injection pressures. To do this, several series of high-speed motion pictures of such sprays were obtained at the Langley Memorial Aeronautical Laboratory, Langley

Field, Va. This report presents the results of the investigation.

Apparatus and Methods

The apparatus used was the N.A.C.A. spray photography equipment which is described in reference 1. A diagrammatic sketch of the injection system is shown in Figure 1. The ball check valve mounted in the open nozzle holder is shown in Figure 2. This system gave one injection of fuel into a chamber with glass windows while 25 electric condensers were successively discharged at the rate of 2,000 per second across a spark gap in a reflector. The light from these discharges was focused by the reflector onto the fuel spray. In the camera a film moving at the rate of 2,000 inches per second recorded a picture of the spray each time it was illuminated by a spark discharge.

The steel injection tube was 50 inches long and had an inside and an outside diameter of one-eighth and one-fourth inch, respectively.

The values of spray-tip penetration were obtained by drawing a smooth curve through the tips of the spray images on each film and then measuring the height of this curve at various time positions. The start of the spray was considered as the point at which this curve intersected a horizontal line drawn through the images of the discharge orifice.

The images of the sprays were examined for distinguishable fuel drops. Nothing more than this could be learned about atomization in the sprays from the examination of the photographs, for, according to Lee (reference 2), the external appearance of a spray gives little indication of the actual atomization or distribution in the spray. Several pictures were taken under the same conditions for each test. The variation in penetration was not large, being about the same as that found by Beardsley (reference 3) when he did not control the initial pressure in the injection tube. The same trouble was experienced with air in the system as discussed in reference 4. The difficulty was eliminated, as before, by carefully filling the line with fuel before each injection.

Tests were made with a 0.020-inch orifice with a length-diameter ratio of 2 and an 0.008" diameter orifice with a length-diameter ratio of 1/2, first with no check valve in the line and then with the ball check valve, which had an opening pressure of 145 to 160 pounds per square inch. The injection pressures were varied from 100 to 500 pounds per square inch. Both atmospheric (0.0765 pound per cubic foot) and 0.325 pound per cubic foot (50 pounds per square inch pressure) chamber air densities were used. The air in the chamber was at room temperature.

The fuels tested were fuel oil and gasoline. The fuel oil had a specific gravity of 0.83 and a viscosity of 0.0221 poise at 100° F. The gasoline had a specific gravity of 0.75 and a viscosity of 0.0079 poise at 100° F.

Test Results and Discussion

Figure 3 shows three series of photographs obtained with the gasoline. At an injection pressure of 100 pounds per square inch the individual fuel drops were visible and the spray cone-angle was indefinite. When the injection pressure was increased to 500 pounds per square inch, the number and size of the visible drops decreased and the cone-angle was 12°. The spray appears to be better distributed and atomized. When the spray-chamber air density was increased from atmospheric to 0.325 pound per square inch, the cone-angle was increased to 15° and the distribution and atomization were apparently still further improved. The appearance of the sprays with fuel oil was similar to those obtained with gasoline.

Enlargements of photographs of the gasoline sprays are shown in Figure 4. At the injection pressure of 100 pounds per square inch the spray consisted of a central core of individual drops surrounded by an envelope of drops of different sizes. The large indistinct drops are probably caused by smaller drops out of focus. At the injection pressure of 300 pounds per square inch there are a few individual drops visible on the edge of the spray, but most of the spray appears to be well atomized. The cone-angle with the gasoline was 3° to 4° greater than with the fuel oil.

Figures 5 and 6 show the effect of injection pressure and of the check valve on the penetration of the sprays from a 0.020-inch orifice. The penetration was in each case greater without the check valve (0 pound per square inch valve-opening pressure) than with the check valve. In each figure the curve for 100 pounds per square inch injection pressure with the check valve in the line is considerably less than than the penetration under the other conditions. This decrease in penetration is caused by the opening pressure of the check valve being greater than the injection pressure maintained in the high-pressure reservoir. (See also reference 5.) For these conditions, under which curves A were obtained, the spray consisted of a stream of drops. With the exception of the 100 pounds per square inch injection pressure, the penetration of the fuel oil was slightly greater than that of the gasoline. (See also reference 6.) The values of penetration compare favorably with those obtained at much higher injection pressures. (Reference 7.)

Figures 7 and 8 show the effect of injection pressure on the penetration of fuel oil and gasoline sprays from an 0.008-inch orifice and a 0.020-inch orifice. As before, the penetration increased with the injection pressure and decreased when the check valve was placed in the line. Comparing the figures, it is seen that the penetration of the gasoline was in some cases greater than that for the fuel oil when the check valve was not in the line. (See reference 6.) This was probably caused by the difference in the flow conditions through the orifice with the two fuels. With the 0.020-inch orifice the Reynolds Number of the flow conditions through the orifice was greater than 2,000 for both fuels. With the 0.008-inch orifice and fuel oil, the Reynolds Number was greater than 2,000 only for the pressures greater than 100 pounds per square inch, but with the gasoline as the fuel the Reynolds Number was greater than 2,000 for all the injection pressures tested. Consequently, with the gasoline the flow through the orifice was well within the turbulent range for all the test conditions; while with fuel oil the flow was turbulent with the 0.020-inch orifice at all the pressures tested, but with the 0.008-inch orifice the flow changed from semiturbulent to turbulent. As the flow conditions with the fuel oil and the 0.008-inch orifice differed, a direct comparison from the standpoint of fuel densities can not be made between Figures 7 and 8.

When the chamber air density was increased from atmospheric to 0.325 pound per cubic foot (fig. 9), the lighter fuel penetrated the greater distance, although the penetration with either fuel was less than that obtained at atmospheric air density. The greater penetration was probably caused, as before, by the change in the flow conditions.

Conclusions

The following conclusions are drawn from the test results presented:

1. Injection pressures below 500 pounds per square inch give penetration rates comparable with the rates obtained with higher injection pressures.

2. Atomization is very poor with 100 pounds per square inch injection pressures, but appears to be fair with 400 and 500 pounds per square inch injection pressures.

3. Atomization and penetration rates change little with orifice size.

4. The penetration rate decreases as the density of the air into which the fuel is injected is increased.

5. Gasoline and fuel oil give about the same penetration rates and external spray appearance.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 4, 1931.

References

1. Beardsley, Edward G.: The N.A.C.A. Photographic Apparatus for Studying Fuel Sprays from Oil Engine Injection Valves and Test Results from Several Researches. T.R. No. 274, N.A.C.A., 1927.

2. Lee, Dana W.: The Effect of Nozzle Design and Operating Conditions on the Atomization and Distribution of Fuel Sprays for High-Speed Compression-Ignition Engines. Report to be published.

3. Beardsley, E. G.: Some Factors Affecting the Reproducibility of Penetration and the Cut-Off of Oil Sprays for Fuel Injection Engines. T.R. No. 258, N.A.C.A., 1927.

4. Rothrock, A. M., and Lee, D. W.: Some Characteristics of Fuel Sprays from Open Nozzles. T.N. No. 356, N.A.C.A., 1930.

5. Rothrock, A. M.: Pressure Fluctuations in a Common-Rail Fuel Injection System. T.R. No. 363, N.A.C.A., 1930.

6. Joachim, W. F., and Beardsley, E. G.: The Effects of Fuel and Cylinder Gas Densities on the Characteristics of Fuel Sprays for Oil Engines. T.R. No. 281, N.A.C.A., 1927.

7. Gelalles, A. G.: Effect of Orifice Length-Diameter Ratio on Penetration and Cone-Angle. Report to be published.

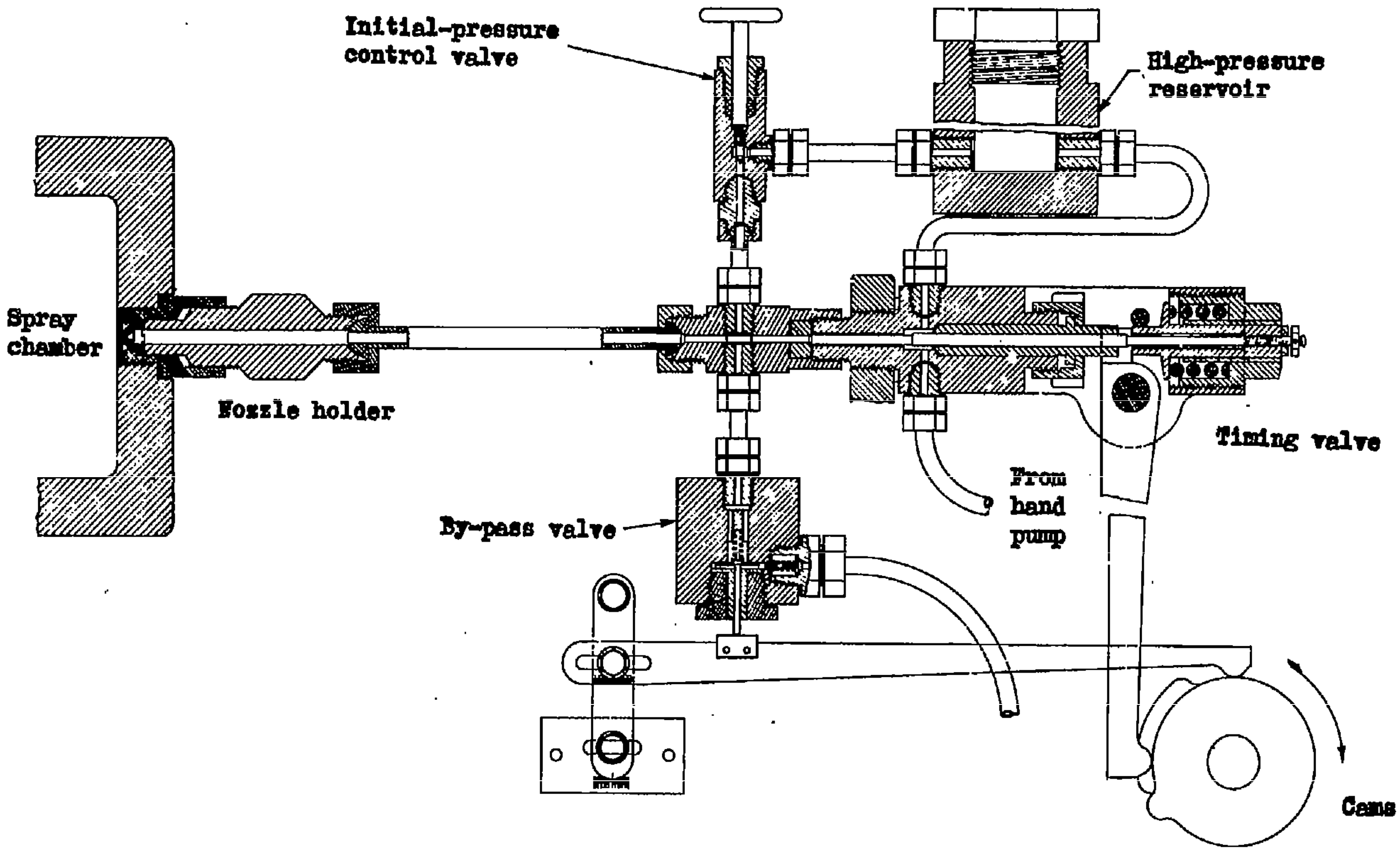


Fig.1 Fuel spray injection system

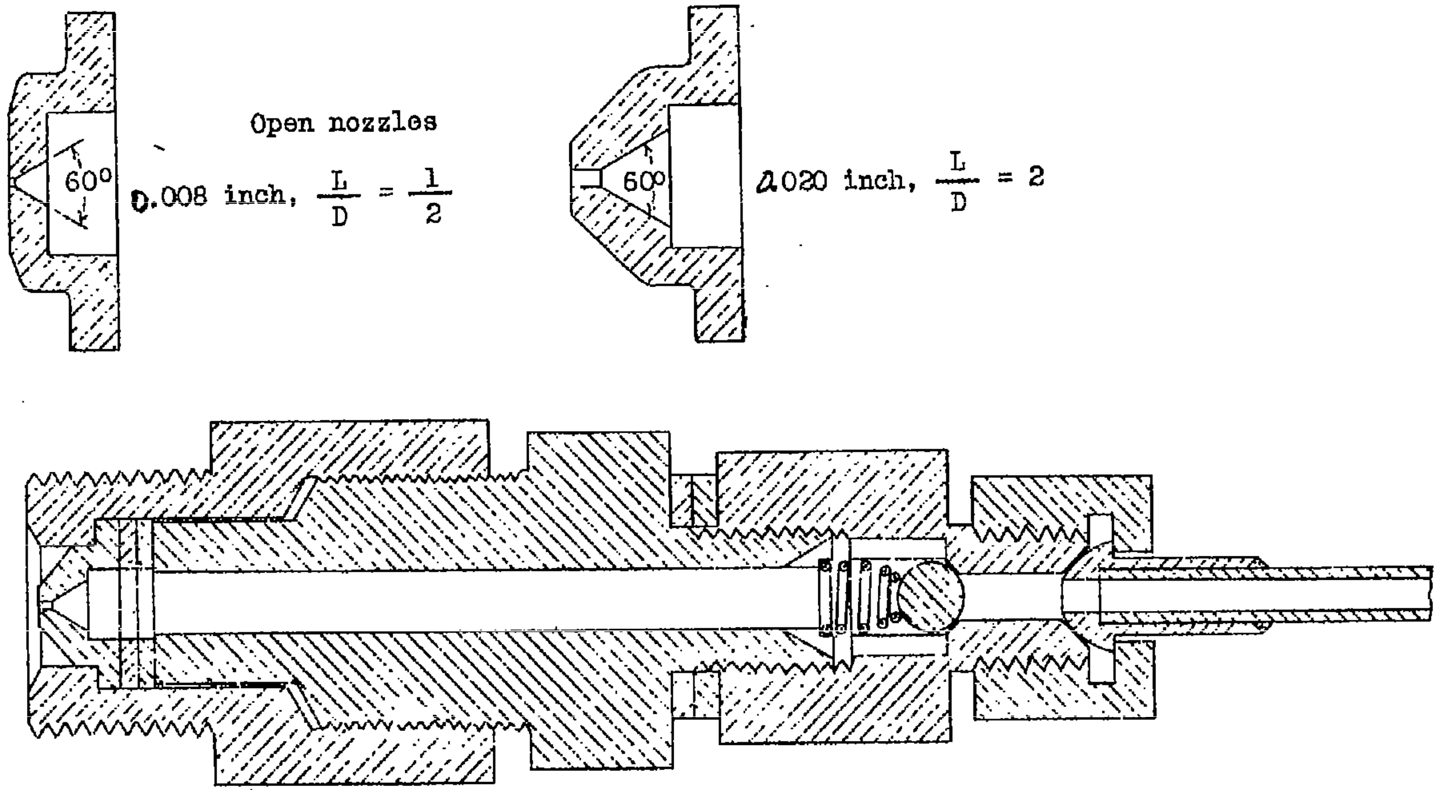
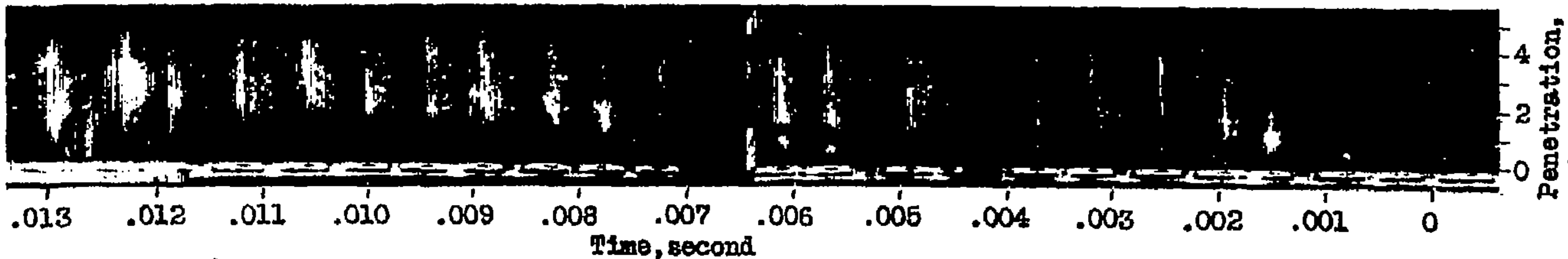
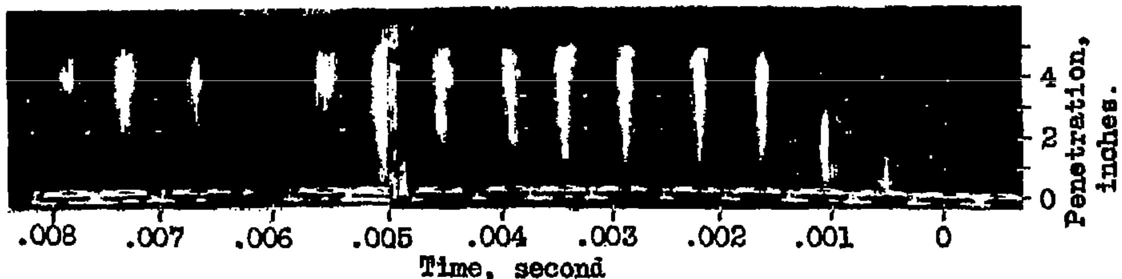


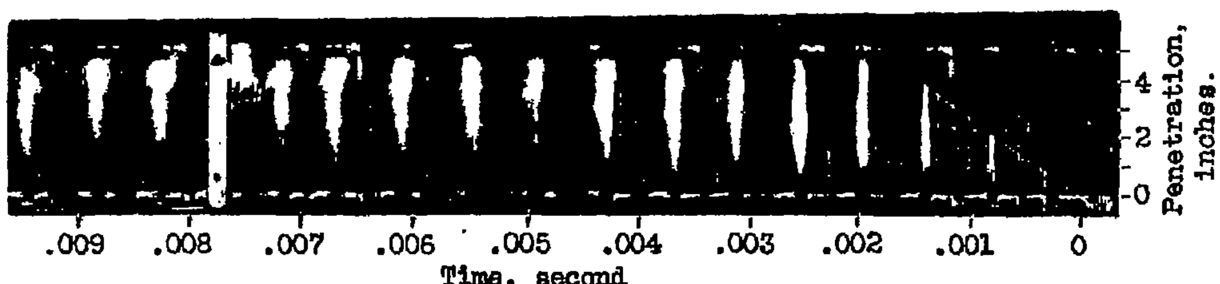
Fig. 2 Open-nozzle holder with ball-check valve



100 lb./sq.in. injection pressure. Atmosphere chamber air density. No check valve.

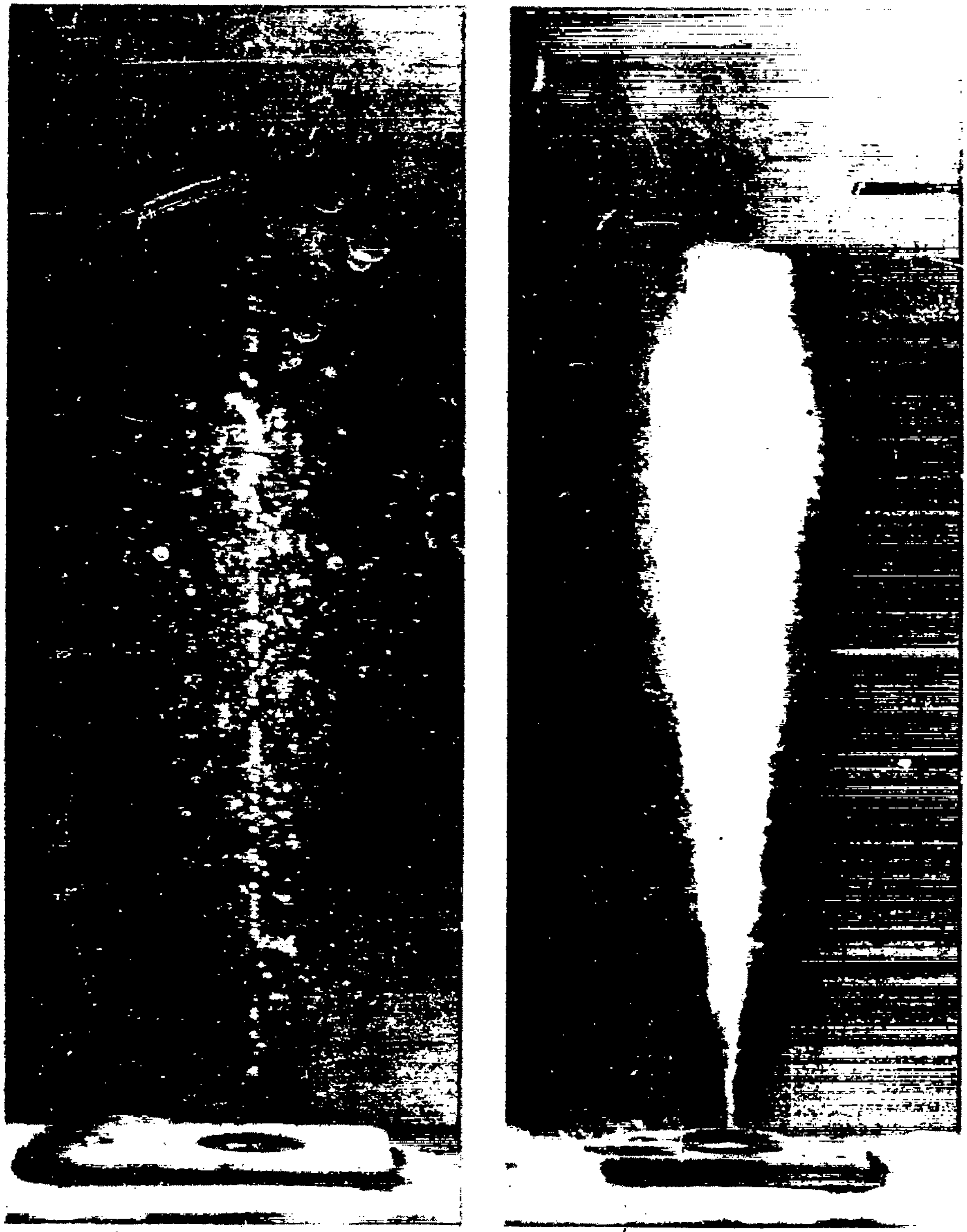


500 lb./sq.in. injection pressure. Atmosphere chamber air density.
No check valve.



500 lb./sq.in. injection pressure. 0.325 lb./cu.ft. chamber air density.
No check valve.

Fig. 3 Gasoline sprays obtained from the 0.020-inch orifice.



100 lb./sq.in. injection pressure 300 lb./sq.in. injection pressure

No check valve. Atmosphere chamber air density.

Fig. 4 Enlargement of gasoline sprays from 0.020-inch orifice

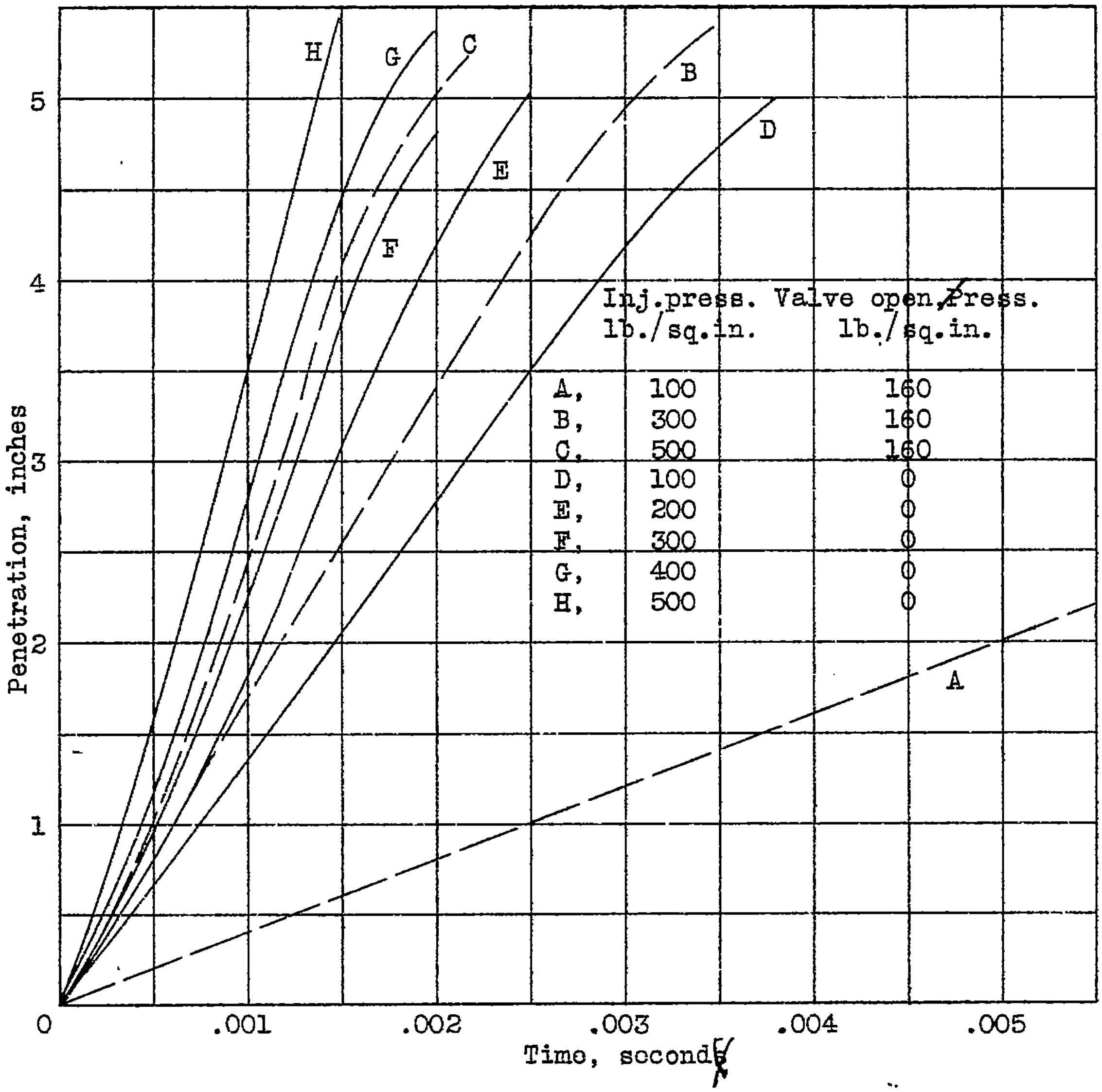


Fig. 5 Effect of injection pressure on penetration. 0.020 inch orifice. Atmospheric chamber pressure. Fuel oil.

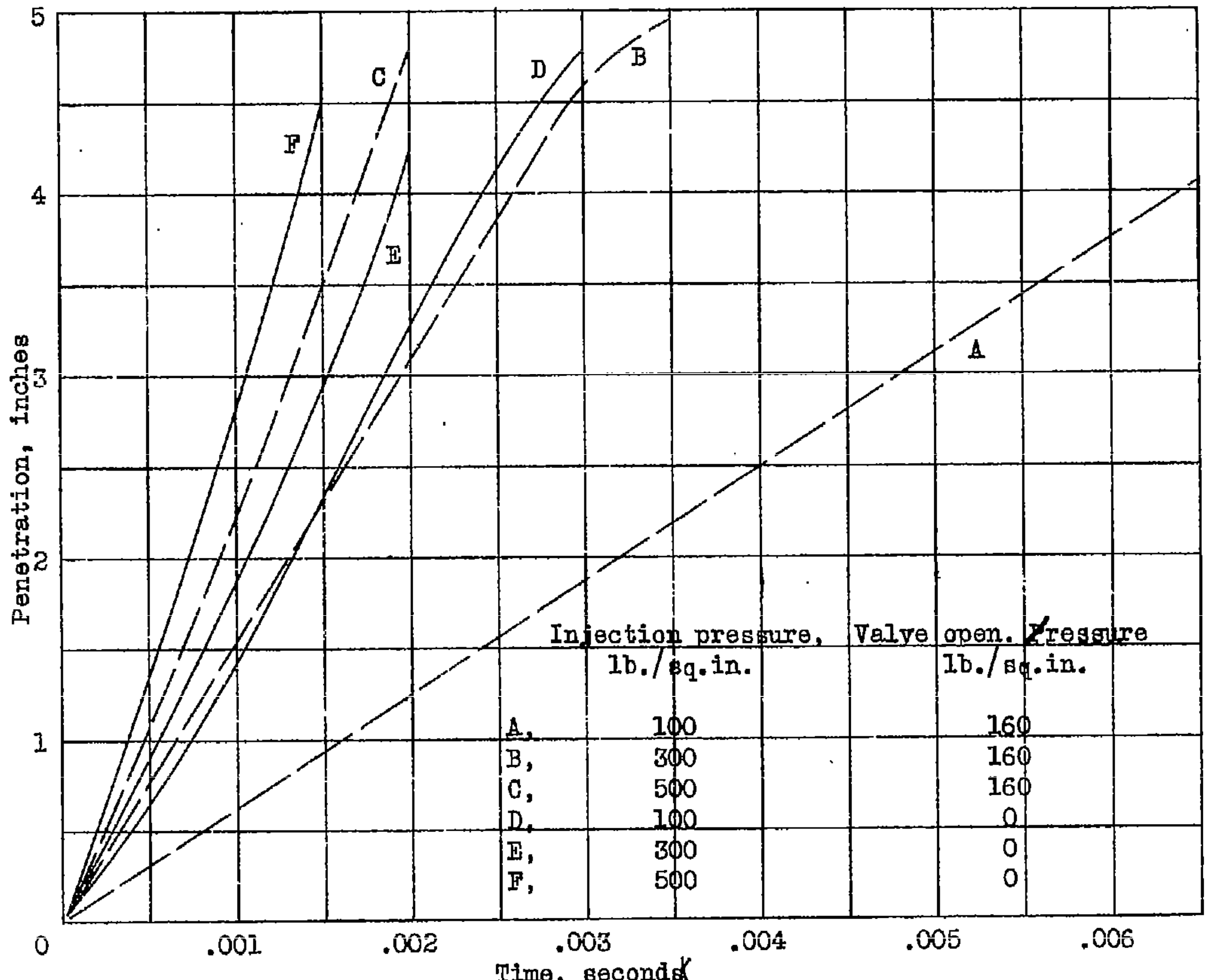


Fig. 6 Effect of injection pressure on penetration, 0.020-inch orifice. Atmospheric chamber pressure. Gasoline

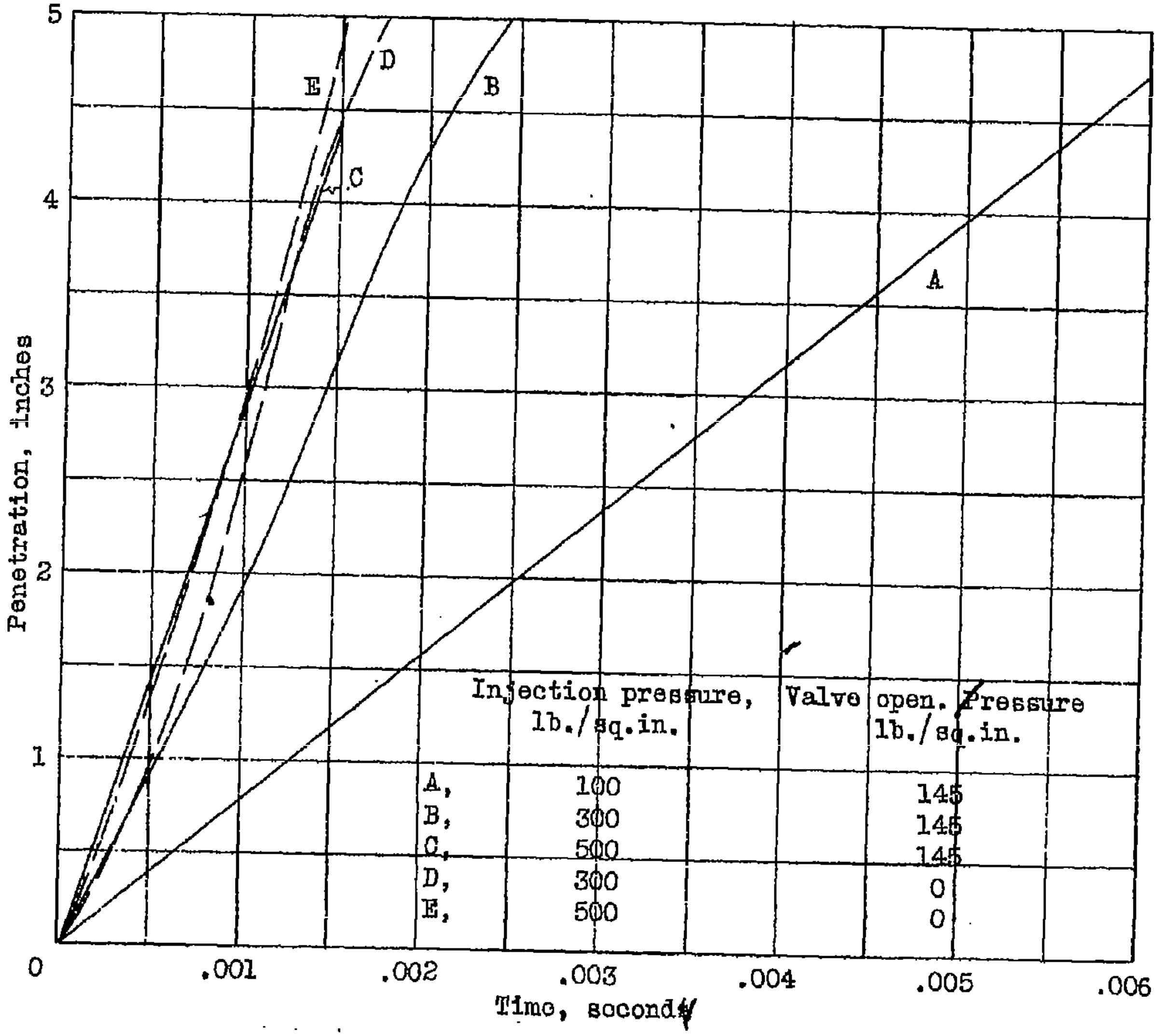


Fig. 7 Effect of injection pressure on penetration. 0.008-inch orifice. Atmospheric chamber pressure. Fuel oil.

	Injection pressure, lb./sq.in.	Valve open. pressure lb./sq.in.
A,	100	160
B,	300	160
C,	500	160
D,	100	0
E,	300	0
F,	500	0

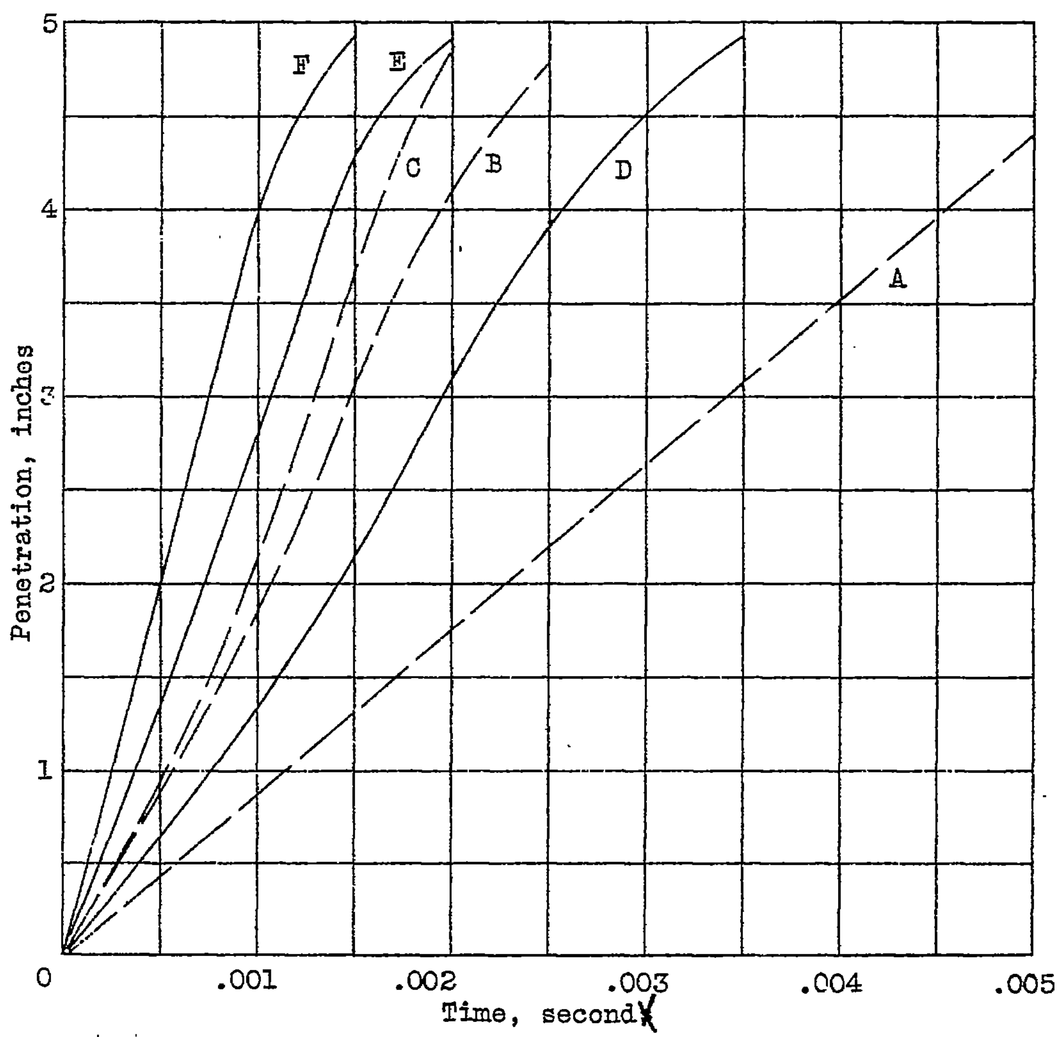


Fig. 8 Effect of injection pressure on penetration. 0.008 inch orifice. Atmospheric chamber pressure. Gasoline

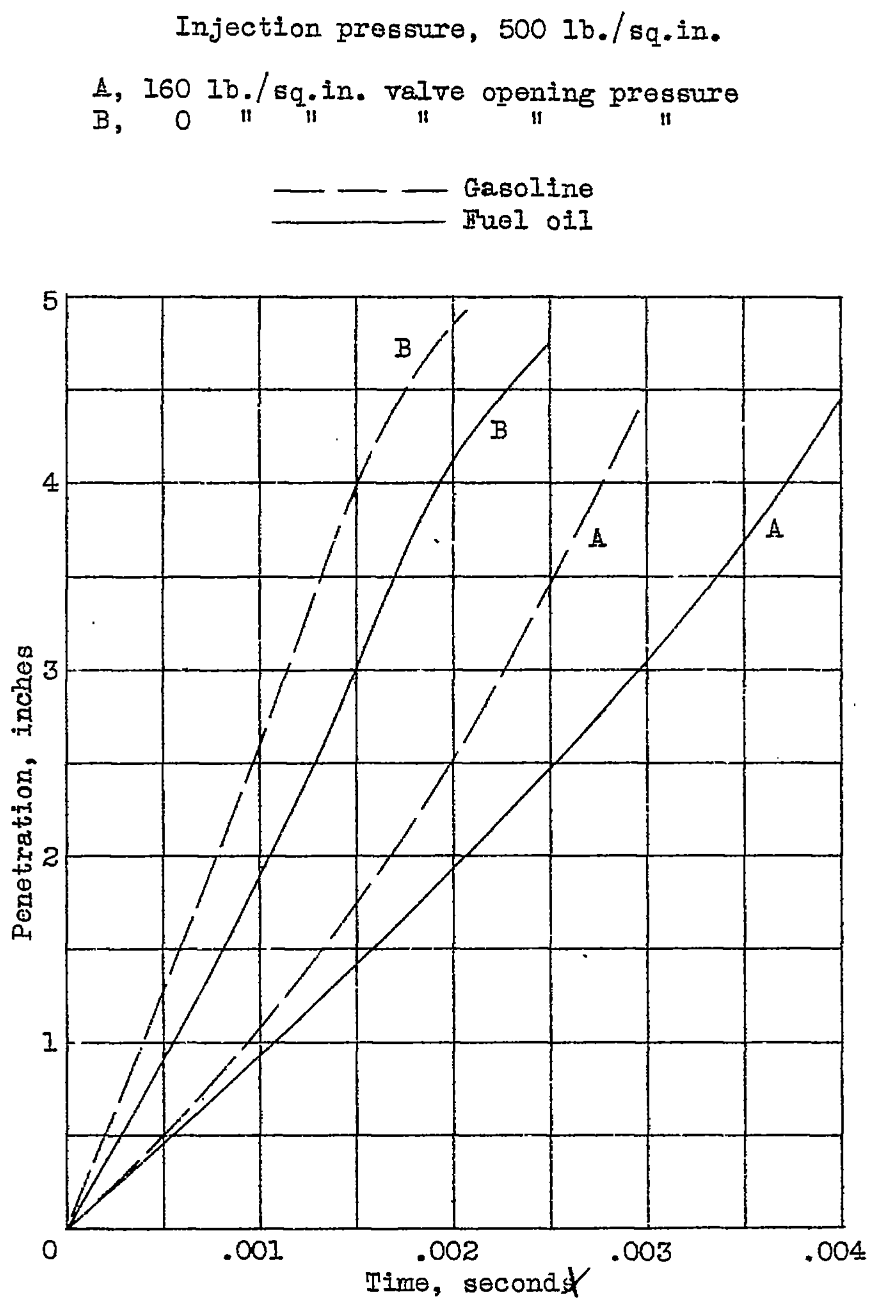


Fig. 9 Effect of injection pressure on penetration. 0.020-inch orifice. 0.325 lb./cu.ft. air density